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Submillimeter Line Astronomy on the NASA Kuiper Airborne Observatory

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This report describes the results of a program of heterodyne submillimeterwave spectroscopy on the NASA Kuiper Airborne Observatory. The components of the program were the continued development of a "Hot electron bolometer mixer receiver," which operated at liquid helium temperatures and was used for the first submillimeterwave spectroscopy of astrophysical sources in the 1 mm to 500 μ m range; the use of the NASA airborne telescope for the first detections of many new interstellar species; the production of many astronomical publications on the nature of the dense interstellar medium.

Several interesting discoveries were made under the auspices of this program. Probably the most exciting was the first detection of the ground state fine structure line of atomic carbon at a wavelength of 609 μ m. Atomic carbon was subsequently shown to be present in considerable abundance throughout the so-called molecular clouds. Other "firsts" included the detection of high J CO lines such as CO (4-3) and fundamental lines of H₂O, NH₃, HCl, H₂D⁺ and several other species. A great deal was learned about interstellar chemistry in molecular clouds.

A list of publications under this program follows:

Publications from this Airborne Program (1980-1989)

- 1) "Detection of the Submillimeter Lines of CO (0.65 mm) and H₂O (0.79 mm)," T.G. Phillips, J.Y. Kwan and P.J. Huggins 1980, IAU Symposium #87, *Interstellar Molecules*, p. 21.
- 2) "Detection of the 610 μ m (492 GHz) Line of Interstellar Atomic Carbon," T.G. Phillips, P.J. Huggins, T.B.H. Kuiper and R.E. Miller 1980, *Ap. J. (Letters)*, **238**, L103.
- 3) "Abundance of Atomic Carbon in Dense Interstellar Clouds," T.G. Phillips and P.J. Huggins 1981, *Ap. J.*, **251**, 533.
- 4) "InSb Heterodyne Receivers for Submillimeter Astronomy," T.G. Phillips 1981, *Proc. SPIE*, **280**, 101.

- 5) "Millimeter- and Submillimeter-Wave Receivers," T.G. Phillips and D.P. Woody 1982, *Ann. Rev. Astron. Astrophys.*, **20**, 285.
- 6) "Atomic Carbon in Orion," T.G. Phillips 1982, *A. N. Y. A. S.*, **395**, 49.
- 7) "Submillimetre Observations of Atomic Carbon," T.G. Phillips and J. Keene 1982, Proc. ESA Workshop on *The Scientific Importance of Submillimetre Observations*, p. 45.
- 8) "First Detection of the Ground State $J_K = 1_0 \rightarrow 0_0$ Submillimeter Transition of Interstellar Ammonia," J. Keene, G.A. Blake and T.G. Phillips 1983, *Ap. J. (Letters)*, **271**, L27.
- 9) "Neutral Carbon in the Egg Nebula," C.A. Beichman, J. Keene, T.G. Phillips, P.J. Huggins, H.A. Wooten, C. Masson and M. Frerking 1983, *Ap. J.*, **273**, 633.
- 10) "Interstellar H_3^+ : Possible Detection of the $1_{10} \rightarrow 1_{11}$ Transition of H_2D^+ ," T.G. Phillips, G.A. Blake, J. Keene, R.C. Woods and E. Churchwell 1985, *Ap. J. (Letters)*, **294**, L45.
- 11) "Chlorine in Dense Interstellar Clouds: The Abundance of HCl in OMC-1," G.A. Blake, J. Keene and T.G. Phillips 1985, *Ap. J.*, **295**, 501.
- 12) "The Abundance of Atomic Carbon Near the Ionization Fronts in M17 and S140," J. Keene, G.A. Blake and T.G. Phillips 1985, *Ap. J.*, **299**, 967.
- 13) "Far-Infrared Spectroscopy of Interstellar Gas," T.G. Phillips 1984, KAO Symposium, NASA Conference Publication #2353.
- 14) "Submillimeter/Far-Infrared Spectroscopy of the Interstellar Medium," T.G. Phillips 1985, Proceedings of the 1984 URSI Symposium on Millimeter and Submillimeter-Wave Radioastronomy, P. 187.
- 15) "Comparison of Submillimeter and Ultraviolet Observations of Neutral Carbon Towards Zeta Ophiuchi," J. Keene, G.A. Blake and T.G. Phillips 1987, *Ap. J.*, **313**, 396.

- 16) "The Abundances of Atomic Carbon Compared with Visual Extinction in the Ophiuchus Molecular Cloud Complex," M. Frerking, J. Keene, G.A. Blake and T.G. Phillips 1989, *Ap. J.*, **344**, 311.